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CIRCUITAL MODELLING IN TRANSIENT REGIME OF ULTRASONIC TRANSCEIVERS FOR IMAGING AND DETECTION INCLUDING NON-IDEAL BEHAVIOURS

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ABSTRACT

The design of efficient ultrasonic transceivers systems for imaging and detection is having a great development at the present time. These systems have demonstrated a great utility in important tasks concerned with the medical and industrial diagnosis. In this paper we present a review and analysis of several Equivalent Circuital Models, proposed for us with the aim of simulating the responses of wideband ultrasonic transceivers, including their piezoelectric, electronic and ultrasonic sections. Modelling of important aspects present in practical configurations, used for medical and industrial diagnostic, are included: Non-linear effects in the emitting-receiving circuits; Non-ideal aspects on the loss and electrical distortions in the electronics; Frequency behaviour of the mechanical losses in the piezoceramic and the propagation medium. Some of the models proposed employ accurate estimated data for the piezoelectric transducers internal parameters. These data were obtained with a new estimation procedure here considered, based on Genetic Algorithms (GAs). PSPICE implementations of these models are presented for simulation in the temporal domain of Through-Transmission (T/T) and Pulse-Echo (P/E) configurations belonging to different imaging dispositions, which consider high-voltage regime and with the real circuital topologies used in the electronic transceivers. Comparison with the experimental data shows a clear improvement in the accuracy of these new models.

INTRODUCTION

Broadband transceiver configurations, operating in Through-transmission (T-T) or pulse-echo (P/E) modes, have been extensively implemented in ultrasonic commercial equipments. Nevertheless, there are still a few aspects concerned with the interaction phenomena of their electronic, piezoelectric and ultrasonic stages, which are not very well known and they need a detailed analysis, in order to include their influences in the global response of the whole ultrasonic system. The analysis and evaluation of the interaction phenomena, in the broadband transceiver structure, involves a great complexity, due to some non-ideal and non-linear behaviours appearing during their operation.

Some circuital models have been proposed for analyzing several aspects of the different stages belonging to an ultrasonic transceiver configuration [1-7].

In this paper, a summary of some results obtained in the modeling of broadband ultrasonic transceiver configurations, which are employed in areas such as industrial NDE and medical imaging, are presented. In the first section, the characteristic and structure of a transceiver configuration is briefly described. Next, some modeling results of three global models implemented by us in PSPICE, and proposed for ultrasonic transceiver systems, are presented and analyzed. A fourth global model, including frequency-dependent acoustic losses in the piezoelectric element and in the propagation medium, as well as typical signal distortions in the electronic stages, is after presented. Finally, comparisons between different simulated and experimental temporal transceiver responses are presented and analyzed.

TRANSCEIVER SIMULATION SCHEMES AND PRELIMINARY APPROACHES

A transceiver configuration, as used in the T-T or P/E operation modes, can be represented by the block diagram in Figure1. [8].

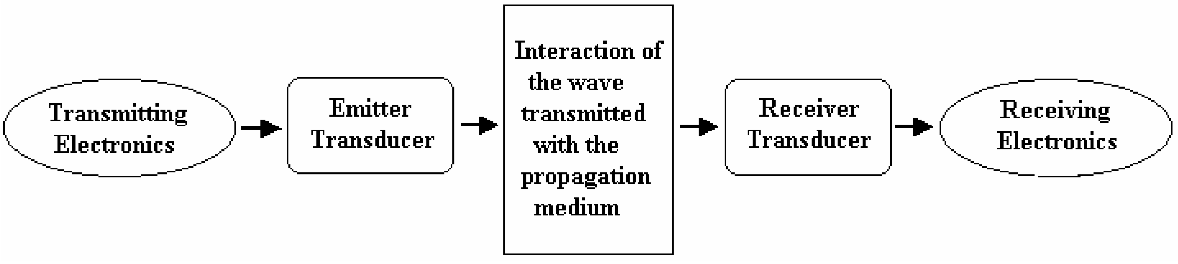

Figure 1. Diagram of a basic T-T / Pulse-Echo configuration.

Diverse physical phenomena such as diffraction, scattering, reflection, attenuation, or others influencing the behavior of the acoustic wave during its travel in the propagation medium, are included in the central block. For the pulse-echo mode, blocks symbolizing the emitter and receiver transducers involve identical properties and parameters of a unique transducer. Additionally, the receiving electronic stage may contain some driving electronics components, which influence the echo signals.

Before presenting the modeling results of this paper, it will be useful to explain very briefly, the order in which these models will be presented. (Figure 2)

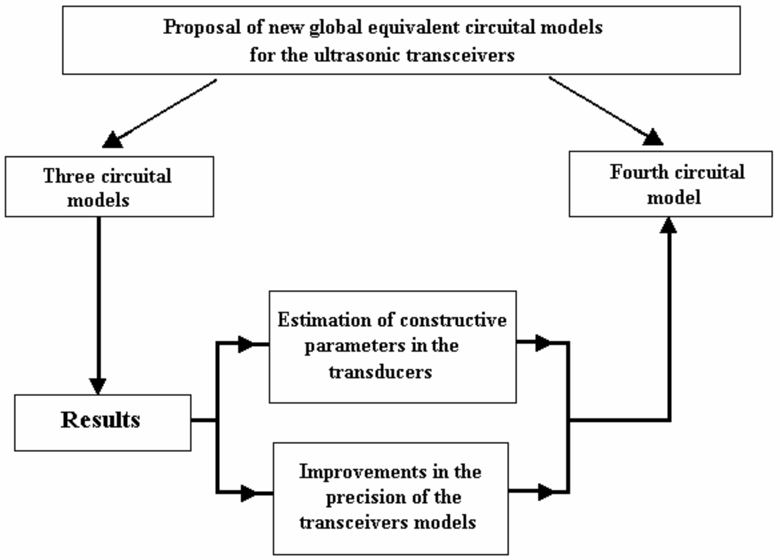

Figure 2. Flux diagram of the modeling process applied to the broadband ultrasonic transceiver.

In a first stage we have proposed three global circuital models. Based on the results achieved by simulation and the discrepancies present in these models with the goals of modeling and simulation that we have proposed, then we followed two parallel work guidelines. These two lines guided us to the presentation of a fourth global circuital model for the broadband ultrasonic transceiver incorporating divers improvements.

Figure 3 shows, in PSPICE format, a T-T scheme which constitutes a basic configuration for low amplitude signals. This scheme was obtained according to Figure 1 and can also be used in (P/E) tests by introducing a few changes. There is an analogy of the different parts of this basic configuration, with the distinct blocks in Figure1.

In order to realize (P/E) tests, the T-T scheme of Figure 3 was modified and two alternative circuital models were also obtained. These two new (P/E) schemes allowed analyzing other important aspects such as: non-lineal effects in the receiving stage [9] and the temporal delay of the received echo [8].

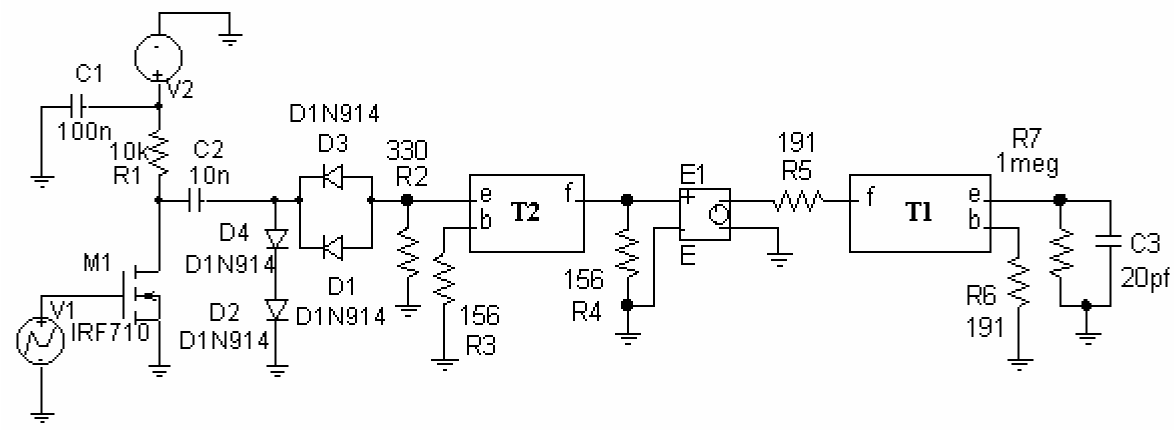

Figure 3. Basic circuital model proposed for broadband ultrasonic transceivers, in (T/T) or (P/E) tests.

The T-T scheme (Figure 3) was employed to model the T-T temporal responses of piezoceramic transducers. The E/R probes (T2 and T1) are symbolized by three-port blocks, which involve two well-known PSPICE models [2-3]. The electrical and mechanical parts of the transducers are denoted by the pins e, b and f. A more detailed description of the ultrasonic transceiver model shown in Figure 3, can be found in [7-8]

First group of simulation results

Figure 4 shows the simulated and experimental T-T responses employing two piezoceramic devices and the basic model of Figure 3. A reasonable agreement between both curves can be appreciated, especially in the time domain waveforms. This agreement was also observed for comparisons done in (P/E) configuration.

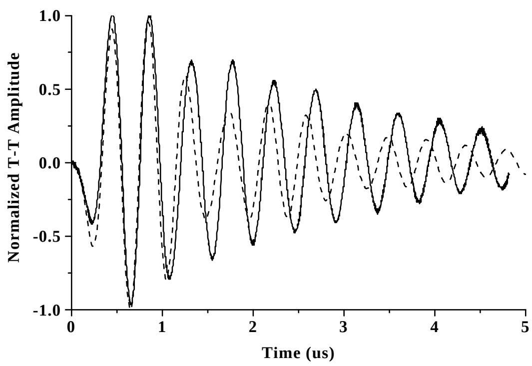

Figure 4. Comparison of normalized through-transmission temporal responses. Dotted line - Experimental. Solid line - Simulated.

In spite of the acceptable similarity between both waveforms, there are notable disagreements in amplitude. In some cases, amplitude deviations that overcame 100 % were registered, as can be appreciated in the Figure 5. This occurs in general for all the simulations made based on these models.

In order to reduce the imprecision in amplitude related to the results obtained by using the three previous models, different improvements were presented and introduced about: the accurate estimation of the constructive parameters of the transducers and the improvement in precision of the models of the transceivers.

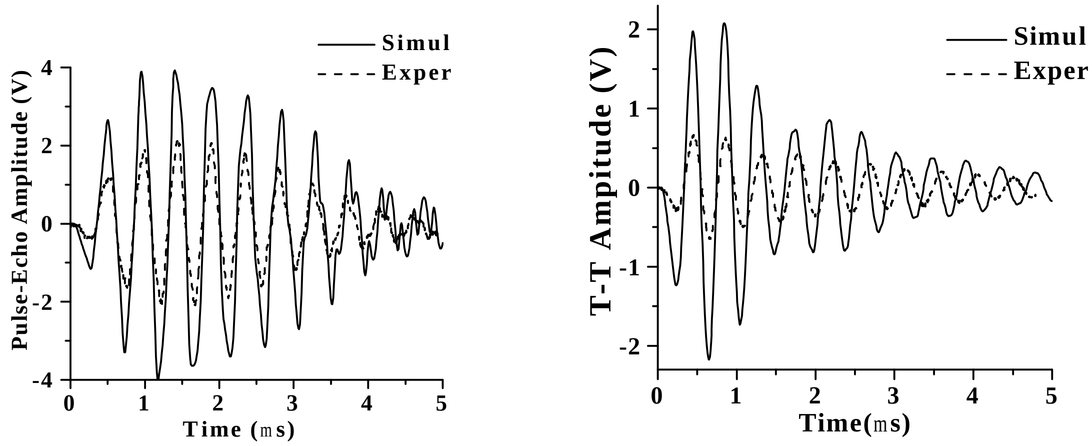

Figure 5. Comparison of Temporal responses. a) Pulse-Echo b) Through-Transmission

TRANSCEIVER GLOBAL MODEL INCLUDING NON-IDEAL BEHAVIOURS

A fourth global model for broadband ultrasonic transceiver was proposed, including a more accurate estimation of the constructive parameters of the transducers [10-11] and an improved precision in the modeling of their different stages [6-7]. This model (shown in the Figure 6) includes a consideration of frequency-dependent acoustic losses in the piezoceramic stages and in the propagation medium, as well as of some signal distortions in the electronic stages. The scheme presented in Figure 6 corresponds to a (P/E) testing, but it can be also adapted for a (T-T) case, doing minor changes in its reception stage. A more wide and detailed explanation about this fourth global circuital model proposed, is presented in [6-7]

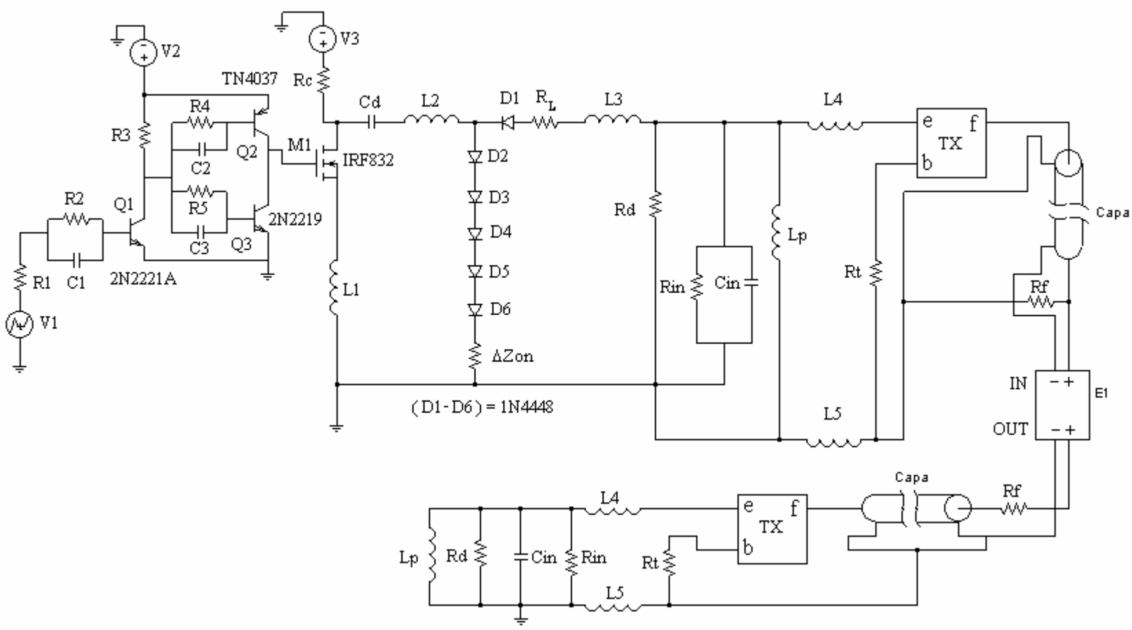

Figure 6. Global circuital model proposed, with an implementation in Pspice format, and including frequency-dependent acoustic losses and signal distortions in electronic stages.

Second group of simulation results

In Figure 7 pulse-echo responses, calculated and measured for the piezoceramic transducer whose properties are presented in [6-7], appear represented for high voltage conditions and emitting in water. These pulse-echo signals are plotted in absolute values. Here, the important

influence exerted on the echo signal by the tuning parallel inductance (Lp in the circuit of Figure 6) had been included in the circuital model.
As a relevant aspect, it can be appreciated as, by using this new improved modeling, a good agreement in echo amplitude can be finally achieved.

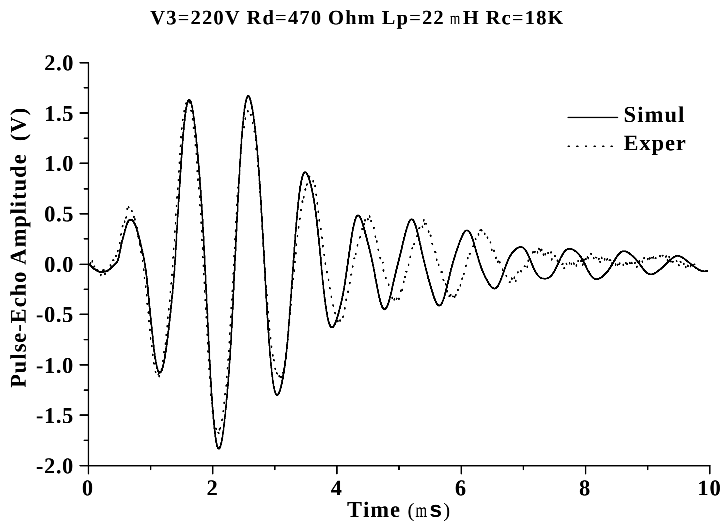

Figure 7. Simulated and Experimental Pulse-Echo responses of a piezoceramic transducer emitting in water. Dotted line – Experimental. Solid line - Simulated.

Finally, the Figure 8 presents a comparison of the simulated and measured pulse-echo signals for a piezoceramic transducer with similar properties to those of the transducer in Figure 7, but with a matching layer in the front face [7]. These echo-graphic signals were obtained for high-voltage driving conditions and for ultrasonic waves traveling in PMMA plastic. A very good agreement between both curves can be clearly appreciated, including the excellent concordance in amplitude and shape of the first three cycles of the theoretic and experimental ultrasonic signals, which are presented in absolute scales.

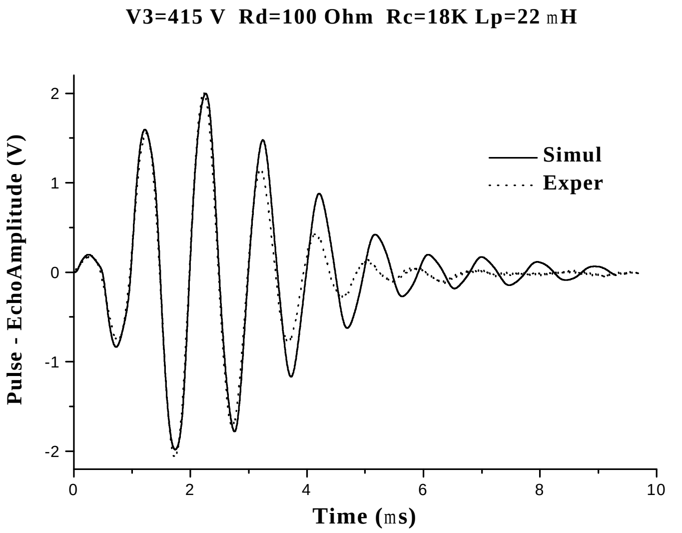

Figure 8. Simulated and Experimental Pulse-Echo responses of a piezoceramic transducer emitting in plastic. Dotted line - Experimental. Solid line - Simulated.

It can be seen as these echoes show a shorter temporal length than in previous figures, which is typical for imaging applications. This shorter length is due to the matching layer effect and the important influence exerted by the selected value for the tuning parallel inductance (Lp = 22 μH), on the frequency band of the echo-graphic pulse. In this case, the applied tuning is close to the compensation value of the transducer clamped capacity.

Conclusions.

Several global circuital models for transient analysis of ultrasonic transceivers for imaging and detection applications has been proposed and applied to real through-transmission and pulse-echo practical configurations. They include some non-ideal behaviours in the electronic and piezoelectric modelling. As a consequence, a more precise prediction of driving and echo waveforms was provided, because these behaviours are normally present in the real NDT and imaging equipments applied in the industry. In particular, some circuital elements originating electric distortions are taken into account, and an alternative implementation to include quadratic frequency-dependence mechanical losses in piezoelectric stages was included for numerical simulation. As a consequence, the final improved model here proposed provides an excellent agreement with the measured experimental responses as is probed in this work, which validates this improved procedure for global modelling and simulation.

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